Report for 2003NJ44B: Seed Dispersal Dynamics in a Restored Salt Marsh: Implications for Restoration Success

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Seed Dispersal Dynamics in a Restored Tidal Marsh: Implications for Restoration Success
Annual Report Submitted to the NJWRRI
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Problem and Research Objectives

With the passing of the 1987 Freshwater Wetlands Protection Act, New Jersey established one of the most stringent and protective wetlands regulations in the United States. However, New Jersey is still experiencing a substantial decline in its wetlands with a loss of over 15,798 acres since 1986 (Balzano et al. 2002). Many of these losses are due to the apparent failure of wetland mitigation, which is the compensation for unavoidable negative impacts to wetland habitat through the restoration or creation of other wetlands. A federal study by the National Research Council (2001) and a state-wide study through the NJ Department of Environmental Protection (Balzano et al. 2002) have found that mitigation practices are not achieving the goal of preventing wetland loss. Mitigation failure is, in part, due to gaps in our ecological understanding of these valuable ecosystems and a lack of rigorous testing of restoration practices (NRC 2001; Balzano et al. 2002). Even in systems with relatively simple community structures, such as salt and brackish marshes, restorations still suffer from the trial and error approaches that plague all wetland restorations (Zedler 1995). To make restoration more successful, methodologies must be rigorously tested in different systems to determine under what conditions they can be effectively implemented (Zedler 2000; Roman et al. 2002). This research, which was supported by the New Jersey Water Resources Research Institute, critically examined one restoration approach (natural colonization) and its application to marsh restoration.

Saline and brackish marshes (tidal marshes) are wetland systems that are flushed daily by two high and two low tides of saline or brackish water. The vegetation of a tidal marsh is characterized by low diversity and distinct vegetation zones that occur within specific tidal ranges (Mitsch and Gosselink 2000). These vegetation bands or zones are generally dominated by one or two clonal graminoids with small populations of other species occurring in infrequent patches (Niering and Warren 1980; Mitsch and Gosselink 2000). The most common approach to tidal marsh restoration is to plant only one or two of the dominant graminoids, such as *Spartina alterniflora*, across the entire site. It is assumed that other tidal marsh species will eventually colonize the restored site as seeds are carried in on the incoming tide.

Predicting the amount of natural colonization that is likely to occur at a restoration site is difficult because the basic ecology of dispersal through tidal flushing in tidal marshes has not been well researched. The few studies that have directly examined the issue of tidal transport in these marsh systems have produced conflicting results. While Koustaal et al. (1987) documented the long distance, mass transport of seeds from a marsh interior, Rand (2000) found little indication of seed movement between different marsh zones. Huiskes et al. (1995) found that although seeds moved out of the marsh in large numbers, very few seeds moved into the marsh system. Seed bank studies of tidal marsh systems have produced similar conflicting results. Several studies found well-mixed, species-rich seed banks that contrasted the zonation pattern of the vegetation indicating strong dispersal forces (Hopkins and Parker 1984; Baldwin et al. 1996);

however, others found seed banks to strongly reflect the vegetation (Hutchings and Russell 1989; Rand 2000; Egan and Ungar 2000).

Based on these dispersal and seed bank studies it appears that secondary dispersal of seeds by tides may, under certain conditions, allow for natural colonization of tidal marshes. The goal of this study was to critically investigate seed dispersal dynamics in a restored urban tidal marsh with the aim of furthering our understanding of the influence of seed dispersal on restoration success. More specifically, I examined whether new species are occurring within the restored marsh, whether tidal inundation and/or position along the main channel are influencing dispersal patterns, and how dispersal patterns relate to vegetation community development.

Methodology

This study was conducted in the Mill Creek Marsh Wetlands Restoration Site (the Site) located in the Hackensack Meadowlands (Meadowlands) of northeastern New Jersey. The Meadowlands is a heavily degraded saline and brackish marsh system. A majority of wetlands within the Meadowlands are dominated by *Phragmites australis,* an invasive wetland species that forms dense monocultures in which few, if any, plant species can exist (Windham and Lathrop 1999; Keller 2000). The Site is a 137-acre tidal marsh that was restored in 1999. During restoration *Phragmites australis* was removed and the site was re-graded to restore the tidal cycle and elevation gradient. *Spartina alterniflora* was seeded and planted in over 30 acres of the low marsh zone.

Seed Input Characterization and Vegetation Community Sampling

To examine the influence of position within the Site, I established 26 sampling stations, 13 around the mouth of the marsh (where the channel enters the Site) and 13 in the marsh interior. At each sampling station three 1 x 1 m plots were established using stratified random sampling, with one plot in the low marsh, one in the high marsh and one in the transitional habitat (transition) between the high marsh and upland habitats. To characterize the seed input, 20 x 20 cm seed traps were placed at the center of each plot in July of 2002, well before most species set seed. To maximize seed input and minimizes trap deterioration, the seed traps were replaced in September 2002 and December 2002, with the final trap collection occurring in April.

Collected seeds were grown out for identification purposes. A majority of tidal marsh plants require cold stratification to break dormancy (Baskin and Baskin 1998); therefore, to maximize germination, traps collected in September and December were kept at 4^{o}C for a minimum of six weeks to mimic the over-wintering process. Traps collected in April were not subjected to this regime because they over-wintered in the marsh. After stratification, the traps were placed in germination chambers and subjected to spring temperature and light regimes (14 light hours at 25^{o}C and 10 dark hours at 15^{o}C). Traps were kept continuously damp with freshwater. As seeds germinated, seedlings were counted and marked with colored toothpicks. Representative seedlings were transferred to soil-filled pots to be grown until they could be identified. The number of seedlings for each species found in a seed trap was recorded. The total seed input for a plot was calculated by combining the data from the September, December and April traps.

Any plots with a missing trap were excluded from the analyses; as a result, there were 17 low marsh plots, 20 high marsh plots and 24 transition plots.

During July and August of 2002 and 2003, the standing vegetation within the 1 x 1 m plots was surveyed, excluding the 400 cm^2 area where the seed traps were placed. Each species found within a plot was identified and its percent cover recorded. The 2002 standing vegetation data was compared against the seed input data to determine the magnitude of secondary dispersal that was occurring in each plot. A comparison of the seed input with the vegetation community of the following year allowed for an examination of how the seed input is influencing the vegetation community.

Experimental Seed Release

During the spring tides of September and October, a seed release experiment was conducted at four locations in the middle portion of the marsh. These spring tides are some of the highest tides of the year and, therefore, represent the largest potential for tidal movement of seeds. At each sampling location, two plots were established, one in the low marsh and one in the high marsh zones. Eight 2-meter long transects extended out from the center of the plots with adjacent transects at 45 degree angles from each other. Two days before the highest tide of the month, dyed seeds (one color for low marsh and one for high marsh) were released at the center of each plot during low tide. 10,000 seeds were released in the high marsh and 1,000 in the low marsh plots. After four days, the number of dyed seeds found at 20-cm intervals along each transect was measured. The data collected for this portion of the experiment is currently being analyzed. From this information I will be able to develop a detailed contour of the seed shadow including the different densities at which seeds are found as well as estimate the number of seeds that have been transported out of the local area due to tidal forces.

Principal Findings and Significance

Seed Input

The seed input for the site was comprised of 54 species including 34 forbs, 13 graminoids and 7 woody species. Twelve of these species have not been previously found within the site; thirteen species were known to occur within the Site but had not been found in any of the plots monitored for this experiment. The twelve species new to the Site represent a mixture of common weedy species and wetland plants. *Typha angustifolia* and *Ranunculus scerleratus* are the only wetland species known to tolerate brackish and saline conditions (Hough 1983; Gleason and Cronquist 1991). *Panicum dichtoflorum* is also a weedy species that is commonly found along the edges of brackish and salt marshes (Hough 1983; Gleason and Cronquist 1991). *Spartina alterniflora* was the only typical dominant clonal graminoid, excluding *P. australis*, to have viable seeds in the seed input. *S. alterniflora* occurred in two plots with one viable seed in each.

The seed input was heavily dominated by forb species, which accounted for over 50% of the seed input in the low and transition zones and 80.2964.74% of the high marsh seeds (Figure 1). The mean relative composition of graminoids was highest in the low marsh zone (46.786 6.06%) with the transition following at 31.726 6.14%. Only 13.5763.31% of the seed input to the high marsh was graminoid species. *Eleocharis parvula*, *Cyperus strigosus* and *Phragmites australis* made up over 91% of the graminoid seed input in each zone. *P. australis* and *Pluchea odorata* were the two most abundant and frequently found species. *P. australis* was found in the seed input of every plot and accounted for 19.0465.49% of the seed input for the low marsh, 7.9363.01% for the high marsh and 23.3265.75% for the transition zone. *P. odorata,* a common aster of tidal marshes, was found in all but one transition zone plot and accounted for 41.9565.71% of the seed input for the low marsh, 31.8365.44% for the high marsh and 30.9465.97% for the transition zone. Other species that dominated the seed input included *Eleocharis parvula,* which contributed to 26.3565.10% of the low marsh seed input, and *Atriplex patula,* which comprised 32.9865.85% of the high marsh seed input.

There was a strong overall zone effect on the magnitude of seed input at the Site that is due to the tidal influence (Wilks' Lambda $F_{2,55} = 4.58$, $p = 0.0004$). The high marsh seed input had significantly more seeds than the other two zones and had significantly more species of seed than the transition zone ($p < 0.02$; Figure 2). The high marsh had almost twice as many seeds in its seed input than the other two zones. The high marsh zone is flooded regularly and, with the exception of strong storm surges or the highest spring tides of the year, is the tidal maximum. As a result, the high marsh is the area in which a majority of plant debris, known as wrack, accumulates. Wrack contains both vegetative and reproductive components of plants, making the high marsh zone a potential collecting area for floating seeds and seed heads resulting in the significantly higher number of seeds (Huiskes et al. 1995; Wolters and Bakker 2002).

Even with the significantly higher number of seeds accumulating in the high marsh zone and the slightly higher total number of species in the seed input, the high marsh did not have more new species occurring in its seed input than either the low marsh or transition zones. This indicates that species are being dispersed around the site in a fairly even manner. An even distribution of seed species could result from the occurrence of several different dispersal mechanisms. Additionally, several studies have suggested that seeds of different weights and shapes will settle out at different tidal inundations (Rabinowitz 1978; Huiskes et al. 1995). These factors may balance the potential for accumulating new species across the three zones, even though larger numbers of seeds collect in the high marsh zone.

Position within the marsh had a slightly significant effect on the total number of species found in the seed input with the interior of the marsh having, on average, 2.3 species more than the mouth (Wilks' Lambda $F_{1,55} = 2.92$, $p = 0.0423$). Because the position effect is only barely significant it should be viewed as a weaker influence on the seed dispersal pattern.

Vegetation Community

The vegetation community of both years had a large forb component similar to the seed input (Figure 3). There was a significant zone effect on the species richness within each year ($F_{2,55} = 16.34$, $p < 0.0001$). For both 2002 and 2003, the high marsh and transition had significantly more species than the low marsh, but were not significantly different from each other. Zone also significantly influenced the average number of new species that became established within a plot ($F_{2,55} = 13.02$, $p < 0.0001$) with the transition having significantly more species becoming established than either the low or high marsh zones. The increase in species richness in the vegetation community between years can be partially attributed to the seed input. When compared to the 2002 vegetation community, the seed input for the three marsh zones had on average 3 to7 more species and included 6 to 7 new species. Even though the high marsh had a significantly more species rich and abundant seed input than the transition zone, it was the transition zone that had the greatest increase in species richness between years.

The discrepancy between the seed input and species establishment is likely due to the harsher environmental conditions of the high marsh in comparison to the transition zone. The high marsh is flooded approximately 20 days out of the month and has waterlogged and sometimes anaerobic soils. In contrast, the transition zone is inundated only once or twice during the course of a year and thus has more aerated soils, which are more favorable to germination and vegetation establishment. Additionally, 2002 was a drought year and 2003 was a very wet year. The vegetation community of the transition zone, which is not regularly flooded, would have been more impacted by a very dry year than the regularly flooded high marsh. Therefore, the large increase in species between 2002 and 2003 in the transition may be, in part, due to the more favorable germination and establishment condition of 2003.

Relationship between Seed Input and Vegetation

A nonmetric multidimensional scaling ordination of the two-year vegetation community data and the seed input, showed that the vegetation community was separating out across the three zones with only slight overlapping occurring between the communities of adjacent zones (Figure 4). The seed input of the three zones overlapped with the vegetation communities, but clustered together more tightly than the vegetation data (Figure 5). Within the seed input cluster, the input of each zone formed individual groups with some overlapping among adjacent zones. The seed input for all three zones also remained close to or overlapped with the vegetation of that zone. This pattern indicates that although there is some mixing of seeds among marsh zones, resulting in the seed input of the zones being more similar than the standing vegetation, the seed input still retains the signature of its zonal community.

Conclusion

The results of this study indicate that although there are a substantial number of new species occurring in the seed input and that there are significant strong zone and weaker position effects, the local signature of the vegetation community and adjacent habitats remains very strong. Twelve seed species (22% of the total number of species in seed) were entirely new to the site. Only three of the new species are tolerant of brackish or saline conditions. Common tidal marsh forbs have readily colonized the site and comprise a large portion of the seed input and standing vegetation communities. Although the forb species are common in tidal marshes they typically occur in small, scattered populations within the larger bands of clonal graminoids. The desired graminoid dominants are not readily colonizing the Site, even though healthy populations of these species are known to occur within the Meadowlands.

Prior studies have found that vegetative reproduction is more important than sexual reproduction for structuring tidal marsh communities and for the colonization of bare patches on the marsh surface (Bertness and Ellison 1987; Shumway and Bertness 1992). Because of the important role that vegetative reproduction plays in tidal marsh community, dominant clonal species may not be producing as many viable seeds as other marsh species, making dispersal a limiting factor to their successful establishment in restored marshes. The population dynamics of *Spartina alterniflora* provides some support for this idea. *S. alterniflora* successfully planted in approximately 30 acres of the Site. Although these populations did set seed in the fall of 2002, only two plots had viable seeds of this species with one seed in each plot.

Phragmites australis is another clonal graminoid for which the viability of its seeds has been under debate in recent literature. In this experiment, I found high numbers of viable *P. australis* seeds through out the Site, which comprised 8 to 23% of the seed input for the three marsh zones. Because this species dominates thousands of wetland acres in the Meadowlands, even with a low proportion of viable seeds, it could still potentially dominate the seed input of a restored sites. To prevent restored sites from returning to *Phragmites*-stands, managers should implement long-term monitoring of these sites for starter populations of *P. australis.*

Reliance on natural colonization to effectively restore saline and brackish tidal marsh systems must be examined carefully. In a highly urban and degraded system such as the Meadowlands, dispersal may be a limiting factor for the dominant components of the target community. Until these dispersal dynamics are better understood, practitioners working in tidal marshes with reduced populations of desired species and distant seed sources should strongly consider planting a variety of species rather than one dominant species.

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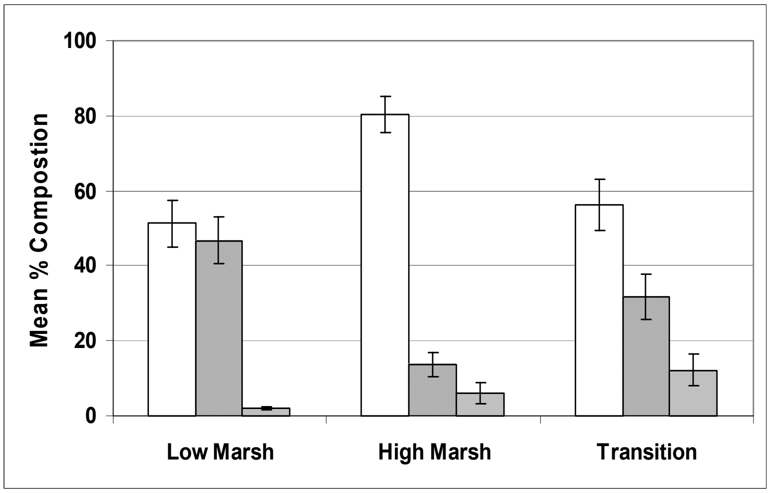

Figure 1. Mean percent composition of the seed input for the three marsh zones. Forbs are represented by the solid white bar, graminoids by diagonal bars and woody species by the solid gray bar.

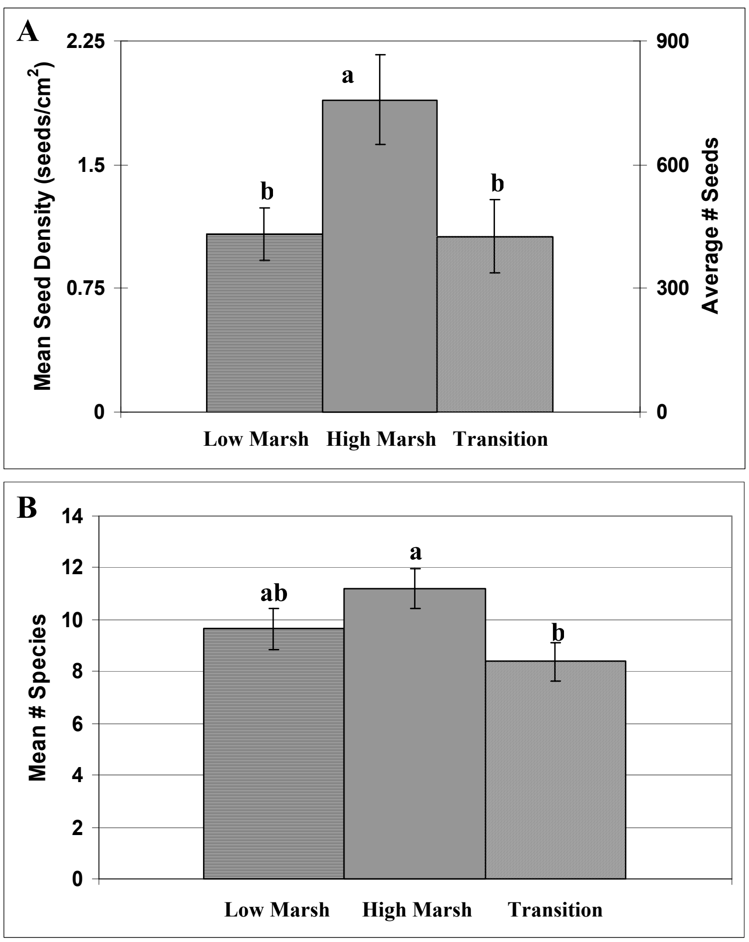

Figure 2. Mean seed density/number of seeds (A) and mean number of species (B) occurring in the seed input for the three marsh zones. Letters correspond to statistical differences found from Bonferroni tests ($p<0.05$).

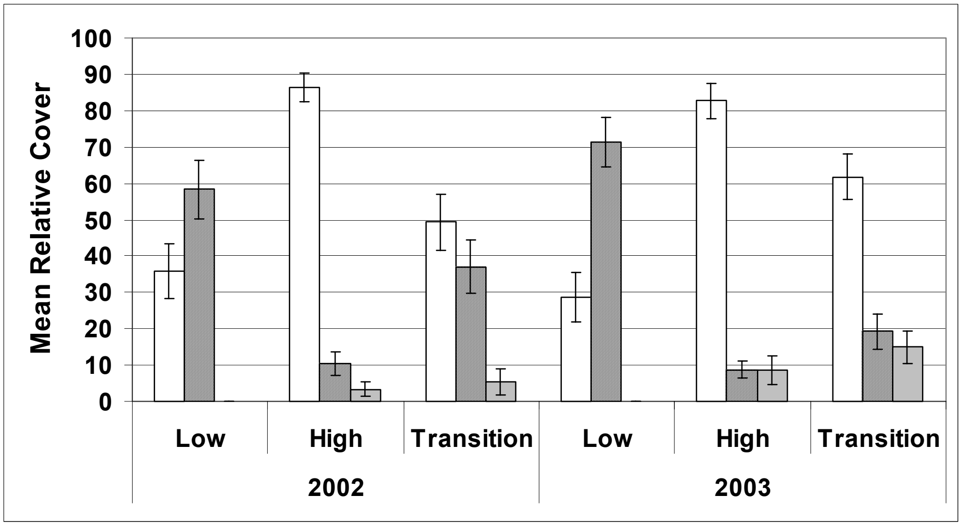

Figure 3. Mean relative cover of the standing vegetation communities found in the three marsh zones in 2002 and 2003. Forbs are represented by the solid white bar, graminoids by diagonal bars and woody species by the solid gray bar.

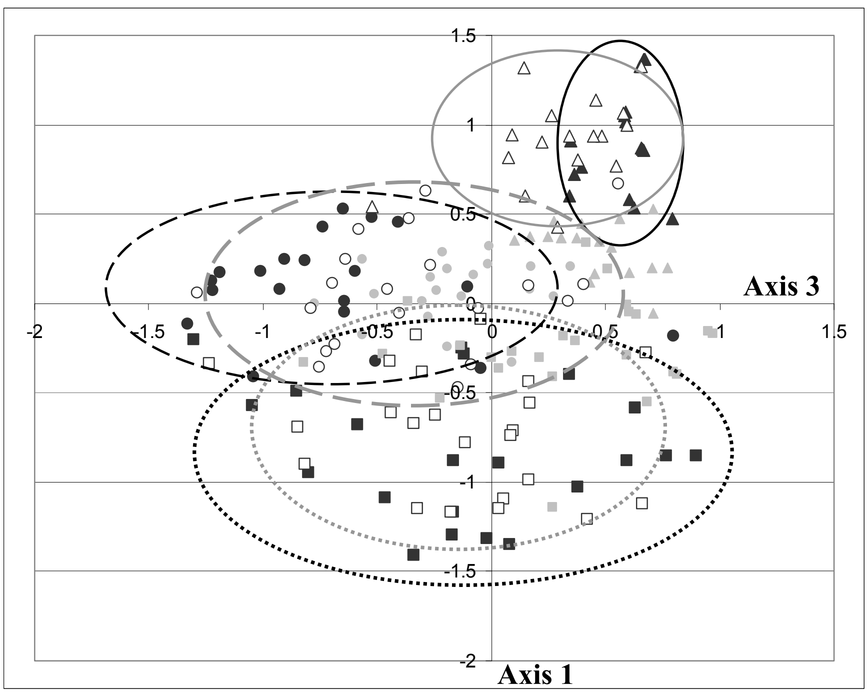

Figure 4. Nonmetric multidimensional scaling ordination of the two-year vegetation community and seed input data. The low marsh data is represented by triangles, high marsh by circles and the transition zone by squares. The 2002 plots are represented by the filled symbols and the 2003 plots by the open symbols; the seed input data is in gray. Lines have been drawn around the vegetation communities of the different zones and years. The solid line represents the low marsh, dashed line the high marsh and dotted line the transition zone. The 2002 lines are black and the 2003 lines are gray.

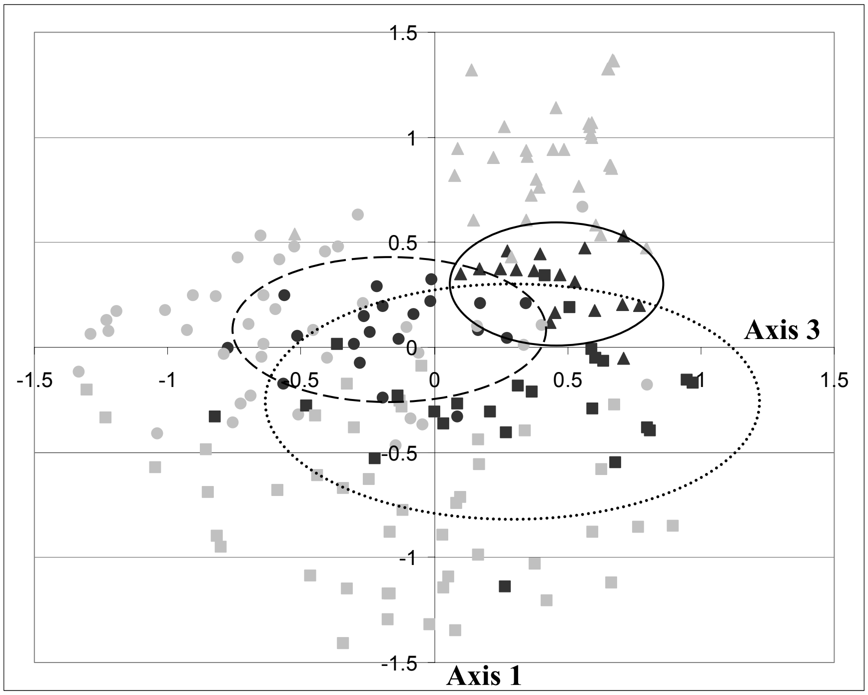

Figure 5. Nonmetric multidimensional scaling ordination of the two-year vegetation community and seed input data. The seed input plot data is in balck and the vegetation data for both years is in gray. The low marsh data is represented by triangles, high marsh by circles and the transition zone by squares. Lines have been drawn around the seed input of the three zones with the the solid line representing the low marsh, dashed line the high marsh and dotted line the transition zone.